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INSTRUMENT CONCEPT FOR GEOPHYSICAL FLUID FLOW EXPERIMENTS ON THE FIRST SPACELAB MISSION

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16. ABSTRACT

A concept is provided for a Geophysical Fluid Flow Cell (GFFC). Sufficient detail is given to allow the start of a GFFC design effort. A brief background of the scientific studies to be conducted with the GFFC and the theoretical basis for GFFC operation are also included.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

CLOSE-UP OF GEOPHYSICAL CIRCULATION CELL

This is a photograph of the concentric sphere fluid flow cell used by Professor John Hart in his research to show that a dielectric fluid with temperature dependent permittivity in a radial electric field with an imposed radial temperature gradient can be used to simulate a radial body force field much like that associated with the Earth, Sun, and planets. The Geophysical Fluid Flow Cell (GFFC) which has been proposed to be flown on Spacelab is based on this concept. This cell is approximately 7 cm in diameter. The gap between the spheres contains the dielectric fluid; the width of the gap is approximately 1 cm. The experiments to be performed in the GFFC, which is similar in size to the cell in this photograph, will yield new data that, hopefully, will permit scientists to answer basic questions concerning the dynamics associated with the general circulations of planetary and solar atmospheres.

TECHNICAL MEMORANDUM 78127

INSTRUMENT CONCEPT FOR GEOPHYSICAL FLUID FLOW EXPERIMENTS ON THE FIRST SPACELAB MISSION

1.0 SCOPE

This document provides the information required to begin engineering design of the Geophysical Fluid Flow Cell (GFFC) proposed for flight on the first Spacelab mission.

1.1 Scientific Background

The GFFC will permit the performance of fundamental experiments concerning baroclinic fluid mechanics on spherical surfaces. The study of the large-scale circulation of Earth, Mars, Jupiter, and Saturn, as well as that of the outer region of the solar atmosphere and the Earth's oceans and fluid core, is primarily the study of thermally driven motion in a spherical shell of rotating fluid. Although there are intrinsic differences with regard to fluid composition and the manner in which the heating takes place, many of the observed large-scale features present in the circulations on these bodies are thought to be related to the interaction of thermally (or buoyancy) induced motions with the latitude dependent Coriolis force. That is, rotational and gravitational forces are major constraints on the flows, but it also appears that the spherical nature of the astronomical bodies plays a very decisive role. Sphericity requires that the cross product $\vec{\Omega} \times \vec{g}$ between $\vec{\Omega}$, the basic rotation vector, and $\vec{g}$, the gravitational acceleration vector, be a function of latitude. Theoretically this latitudinal dependence seems to be crucial to the existence of equatorial accelerations. These have been observed on the Sun [1-1] and on Jupiter [1-2] and have been well documented on the Earth where they are known as the Cromwell current and the Berson westerlies. Many theories [1-3 — 1-6] which attempt to explain some of these observations have appeared in recent years. In all theories, it is clear that the variation of Coriolis parameter with latitude is an important factor, as one would expect from the large scales of the flows being discussed.

In the past, scientists have pursued the understanding of large-scale planetary circulations so necessary for effective prediction via four approaches: analytical and numerical simulation, laboratory simulation, and direct observation. Each method has its limitations. The theories contain a number of idealizations and assumptions. The flows being modelled are three-dimensional, time-dependent, and range over many length scales; thus, simplifications are necessary even in large numerical simulations using the basic equations and integrated on our most advanced computers. This situation suggests that considerable insight into the fundamental problems of global circulation might be obtained by simulation in a real physical system which retains all, or almost all, of the essential physics. Under normal circumstances one would think that controlled laboratory experiments would contribute; however, it has been impossible to model the Earth's sphericity properly in the laboratory over anything more than a few degrees in latitude. Spurious background currents are set up in experiments unless $\vec{\Omega}$ is parallel to $\vec{g}$. Since $\vec{g}$ is unidirectional in the Earth laboratory setting, many essential physical phenomena which depend on latitude variation of $\vec{\Omega} \times \vec{g}$ are omitted (e.g., there is no equatorial region in the classical dishpan experiments of Hide [1-7] nor were equatorial planetary waves properly modelled). It is interesting to note that such mean accelerations as the equatorial jets are not observed in laboratory experiments on uniform thermal convection with rotation [1-8] where the rotation vector is exactly aligned with gravity. The almost zero-g environment of the Earth-orbiting vehicle offers an opportunity to conduct experiments with the necessary physical symmetries, especially a radial "gravity" field such that the $\vec{\Omega} \times \vec{g}$ effects are included exactly as they appear on the Earth, planets, and Sun.

Of the many fundamental features observed in planetary circulations, possibly the most important one to explain is the previously mentioned differential rotation that seems to result from equatorial accelerations of fluid in the convection zones. Although some progress has been made in analytical and numerical approaches to the related astrophysical and geophysical fluid dynamics problems, it has not been possible to test any of the theoretical approximations because, as mentioned previously, terrestrial physical experiments cannot be done except for the case where $\vec{\Omega}$ is parallel to $\vec{g}$. The spherical convection experiment will provide badly needed information on preferred scales and mode structure. Since many computer and analytical models rely on limited mode representations to get solutions, it is most important to identify which modes dominate in the real physical system and what their mutual and self interactions are. Progress in our understanding of these fundamental fluid dynamics problems will enhance our understanding of our own atmosphere.

The GFFC will permit the performance of a class of experiments which will focus on one particular geophysical fluid dynamics problem, namely that of the generation of mean flows by thermal eddies. For this first zero-g experiment, the simplest geometrical configuration, which is perhaps more applicable to simulating solar convection than to modelling baroclinic instabilities in the atmosphere has been chosen. However, the fundamental knowledge gained from studying the problems with the simplest geometries and symmetries will be more useful for demonstrating the effectiveness of zero-g space platforms as a base for laboratory simulation of astrophysical and geophysical flows and, in particular, aspects of the general circulation of the Earth's atmosphere and oceans and the Sun.

2.0 INTENT

This document is intended to promote the development of the GFFC proposed for flight on the first Spacelab mission. More specifically, it is intended to provide sufficient information to begin a preliminary design effort. This information is largely presented in the form of descriptions and requirements. The descriptions are intended to provide a basis for better understanding of the requirements which follow. The descriptions are not to be construed as a preliminary design. It is anticipated that the actual preliminary design will deviate from the concept presented herein as the factors of feasibility, performance, cost, and time are addressed by the design team.

3.0 DESCRIPTION

The GFFC is a device for providing, measuring, and recording stratified fluid flows in spherical geometries under controlled conditions in the Spacelab (Figs. 3-1 and 3-2). The flows are generated in a fluid contained between two concentric, electrically conductive spheres. The flow characteristics are determined by the electric field and temperature gradients impressed across the concentric sphere gap as well as by the rotation rate of the spheres. The fluid (Dow-Corning 200 silicone oil) has a dielectric constant which is temperature dependent so that upon application of a voltage between the spheres an electric field will occur, and upon application of a radially directed temperature gradient a radially directed body force will act on the fluid in a manner exactly analogous to the gravitational body force that acts on the Earth's oceans and atmosphere [3-1]. The appendix provides a theoretical basis for the simulation of gravitational body forces with dielectric fluids in electric fields. To permit observation of the flow field in the GFFC, the "northern" hemispheres of the inner and outer spheres of the GFFC are transparent (Pyrex glass) with longitudinal and latitudinal grid lines inscribed on the interior surface of the inner sphere. A light source is located at the center of the flow cell in such a manner that, to an external observer, these lines appear distorted as a function of the flows existing within the concentric sphere gap and thus constitute a measure of the flow field. A film camera is utilized to provide a permanent record of the distortion patterns.

3.1 Test Description

In this document the term test refers to a sequence of 10 events or experiments conducted automatically by the GFFC based upon operator programming. For each test the spin rate and inner sphere temperature are held constant while the voltage is sequenced through a series of 10 steps. The fluid flows and data recordings which occur during each step constitute an experiment. At test completion, the operator must reprogram the instrument if further tests are desired.

3.2 Functional Description

Electrically, the GFFC may be considered to be comprised of the following functional components (Figs. 3-3 and 3-4):

- Sequencer
- High voltage supply (HVS)
- Spin motor control system (SMCS)

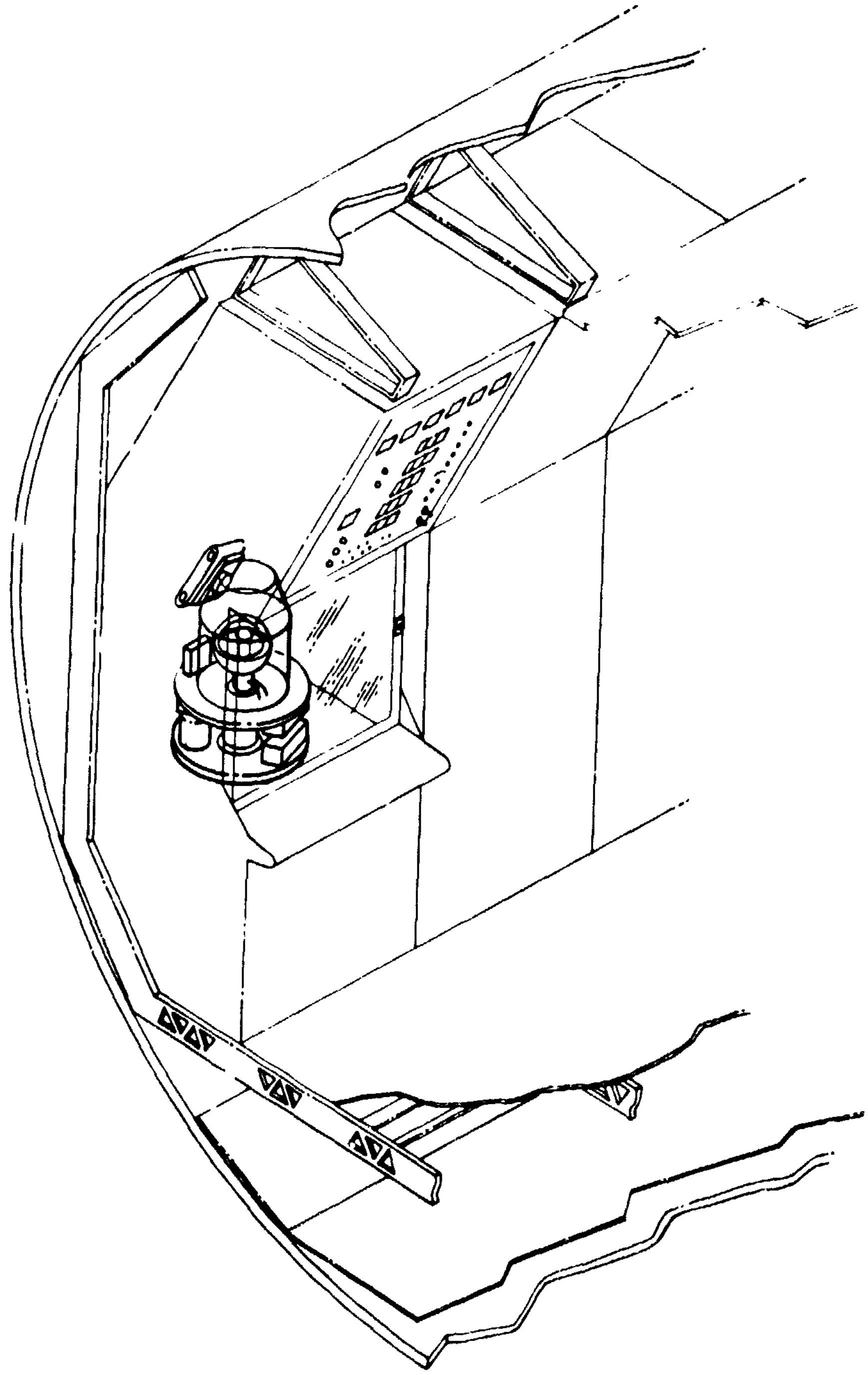

Figure 3-1. Artist concept of GFFC in Spacelab.

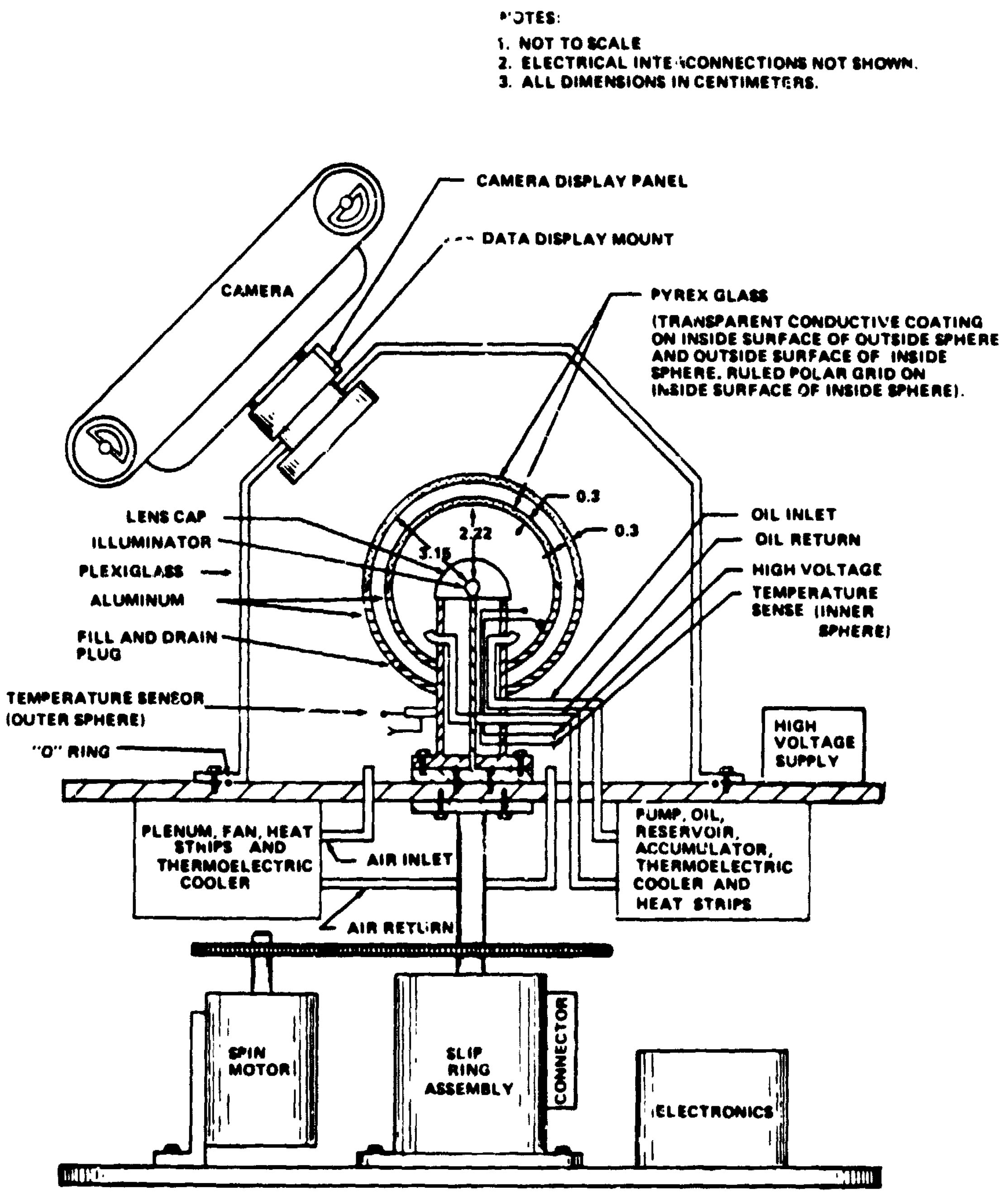

Figure 3-2. Conceptual mechanical layout.

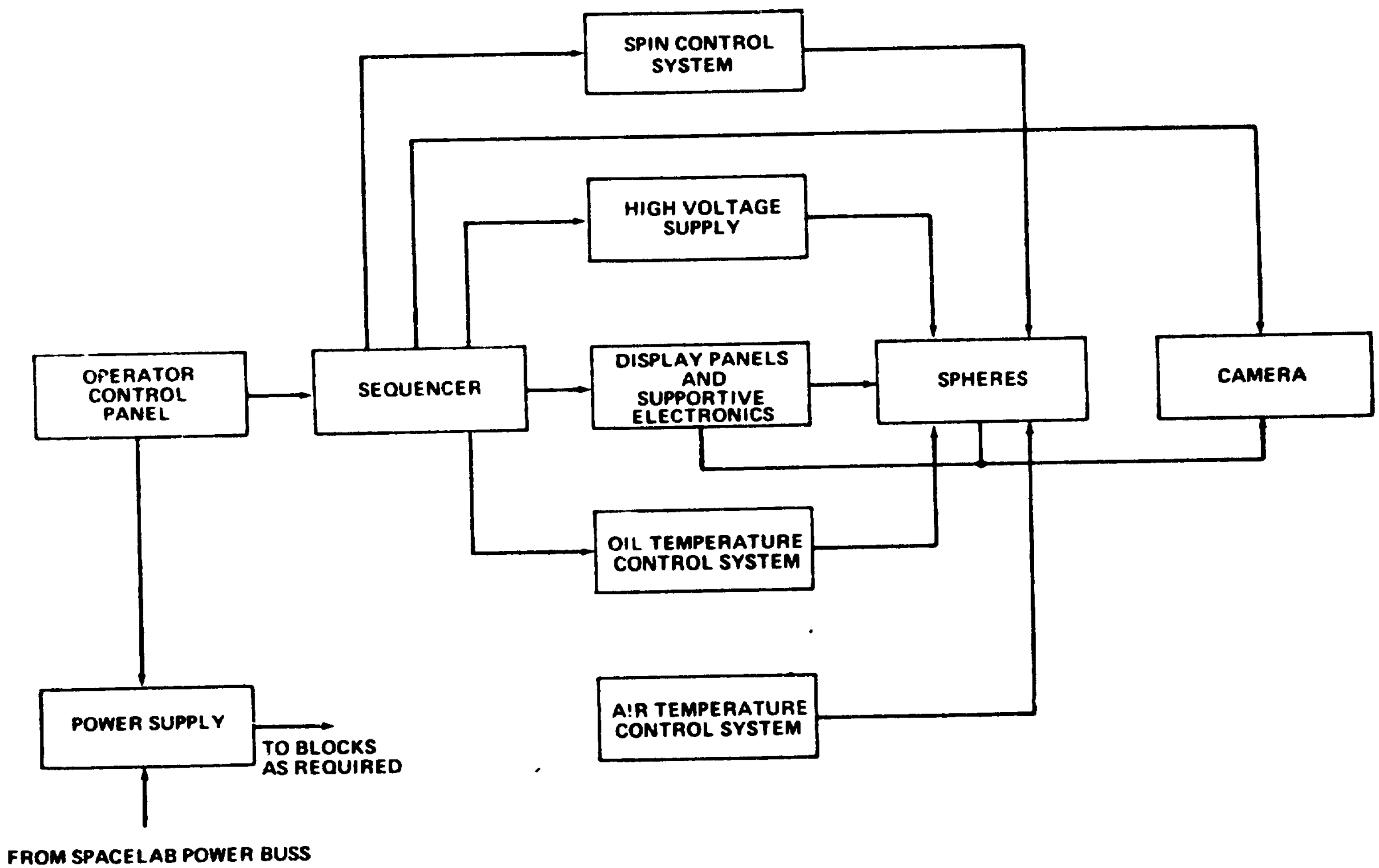

Figure 3-3. Functional block diagram (general).

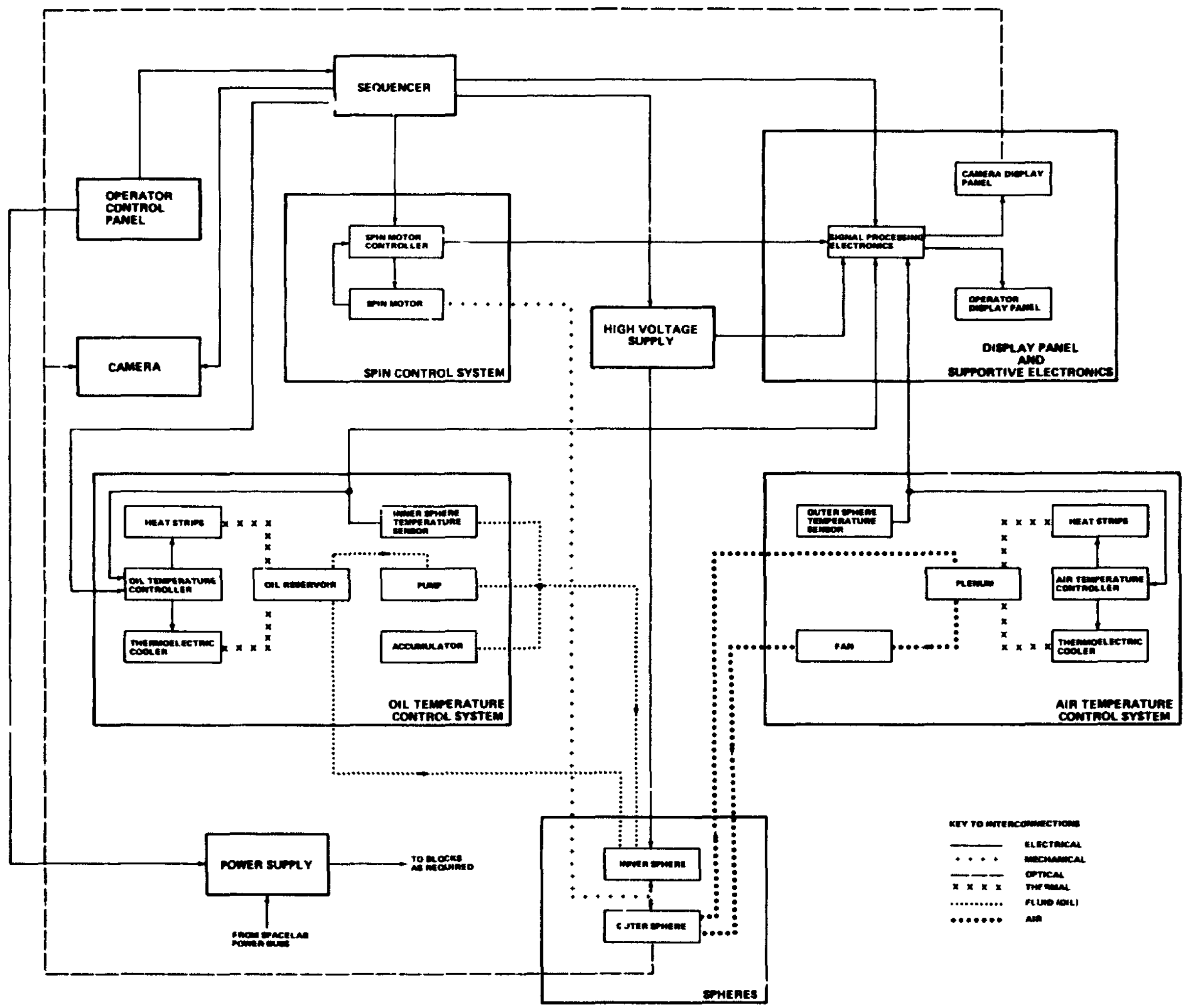

Figure 3-4. Functional block diagram (detailed).

- Oil temperature control system (OTCS)
- Air temperature control system (ATCS)
- Signal processing electronics (SPE)
- Operator control panel (OCP)
- Operator display panel (ODP)
- Camera display panel (CDP)
- Power supply

The sequencer serves as the master controller for the GFFC. Based upon programming and operating commands received from the OCP, the sequencer automatically directs the operation of much of the remainder of the GFFC. The sequencer is described in further detail in Section 3.3.1.

The HVS provides the electric field which is maintained across the dielectric fluid. Its output voltage (thus the electric field strength) is determined by programmed command. This command is entered at the OCP and is communicated to the HVS by the sequencer. The HVS is described in further detail in Section 3.3.2.

The OTCS is comprised, in part, of an Oil Temperature Controller (OTC) and thermal heating and cooling elements. The OTC provides operating signals to the thermal elements to maintain the inner sphere oil temperature (hereafter referred to as the inner sphere temperature) at the programmed level. This level is entered at the OCP and is conveyed to the OTC by the sequencer. The OTCS is described more fully in Section 3.5.

The ATCS is comprised, in part, of an Air Temperature Controller (ATC) and thermal heating and cooling elements. The ATC provides operating signals to the thermal elements to maintain the environment of the outer sphere (hereafter referred to as the outer sphere temperature) at 25°C. The ATCS is more fully described in Section 3.5.

The SMCS is comprised of the Spin Motor (SM) and the Spin Motor Controller (SCM). The SM turns the inner and outer spheres in unison via mechanical drive (see Section 3.4). The SMC provides the operating signal to the SM. The magnitude of this signal determines the motor shaft speed and is a function of programmed command. This command is entered at the OCP and is transmitted to the SMC by the sequencer.

The SPE receives signals from various points throughout the GFFC. These signals contain experiment data and GFFC status information. After appropriate electronic processing, these signals are conveyed to the OCP and CDP. Here, through various panel indicators, experiment data and status information are made available to the camera and GFFC operator (see Sections 3.6.3 and 3.8.1).

The OCP is the entry point for all GFFC programming and operating commands. A specific description of the OCP controls and switches utilized to enter these commands is given in Sections 3.6.1 and 3.6.2.

The power supply operates from the Spacelab-provided power distribution system and generates the voltages required to operate the GFFC.

3.3 Electrical Description

The electrical description of the GFFC is limited here to the sequencer and HVS. Their operation is sufficiently unique to warrant special consideration. The remainder of the GFFC electronics implements functions well known to the electrical engineer and need not be dwelled upon.

3.3.1 Sequencer Description

The sequencer (Fig. 3-5) may be considered to be comprised of a memory section and a timing and control section. The memory section consists of 12 storage registers and a 10-channel multiplexer (MUX). Ten of the 12 registers are dedicated to storing voltage commands. The remaining two are dedicated to storing spin rate and temperature commands, respectively. Information is transferred into memory by depression of the appropriate LOAD control pushbutton switches. Since only one LOAD pushbutton switch is provided for the 10 voltage registers, a rotary switch is used to provide register addressing.

Each voltage memory register is connected to a separate MUX channel. The MUX conveys the stored data, one register at a time, to the SPE and HVS. The SPE processes the data and applies it to the ODP and CDP for display and imaging (see Sections 3.6.3 and 3.8.1). The HVS utilization of the data is described in Section 3.3.2.

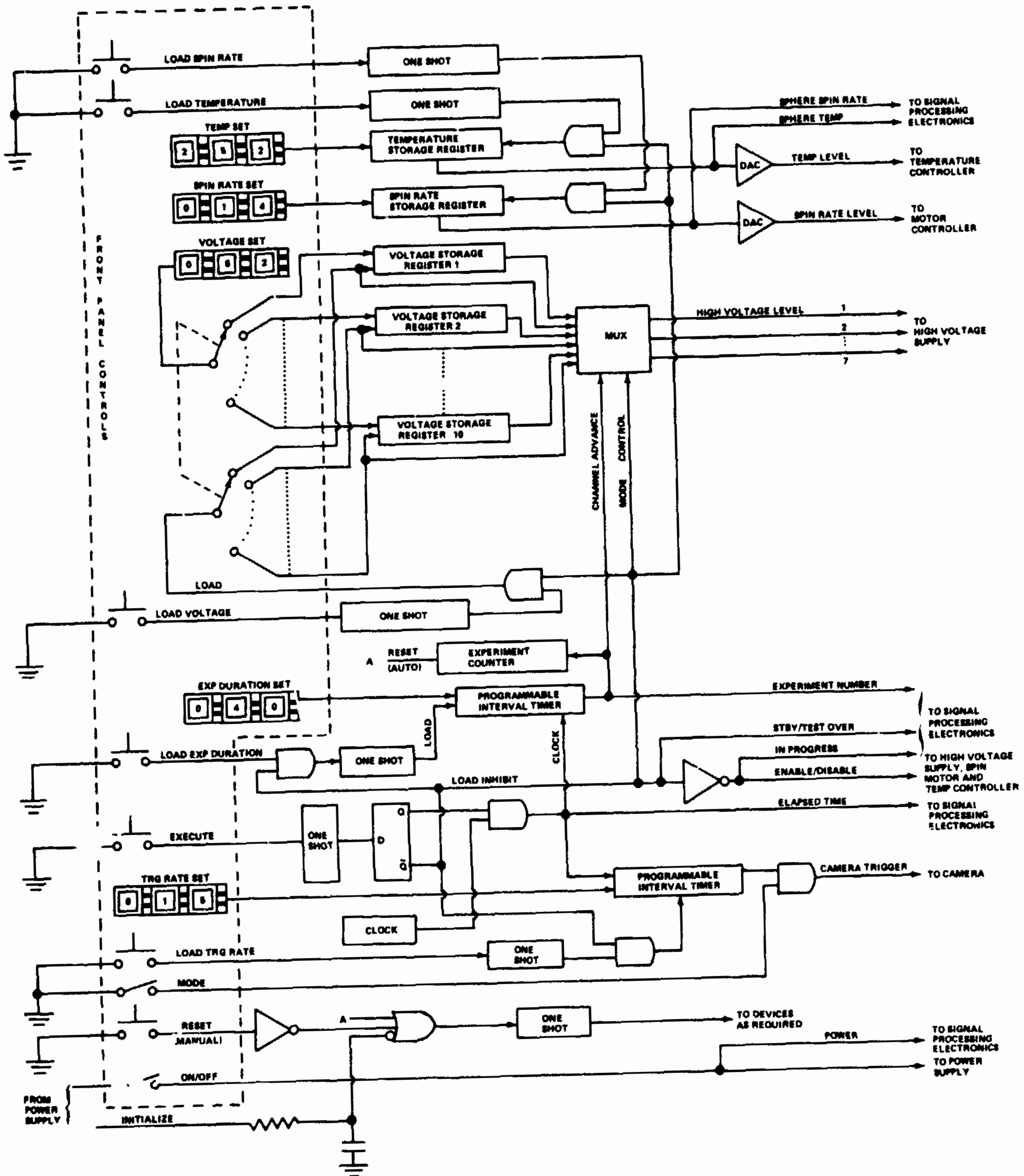

Figure 3-5. Sequencer.

MUX channel selection is provided by control signals. These signals have two origins. When a test is not in progress, the control signals originate from a set of contacts on the rotary switch. These contacts activate the MUX channel corresponding to the addressed memory register (previously mentioned) and thus allow visualization of the entered command on the ODP.

When a test is in progress, the control signals originate from the timing and control circuitry. These signals direct the MUX to apply the contents of the 10 voltage storage registers sequentially to the SPE and HVS. The SPE and HVP utilization of the data is as previously described.

The data in the spin rate and temperature registers are applied to subsequent circuitry via digital-to-analog converters (DAC). These data are also conveyed via the SPE to the ODP and CDP for display and imaging.

The timing and control section is comprised of a flip-flop, logic gates, clock, two interval timers, reset and initialization circuitry, and one-shots.

The flip-flop is under control of the EXECUTE pushbutton switch. Its depression results in the reversal of flip-flop polarity. This reversal has four consequences:

a. MUX control is transferred from the rotary switch to the timing and control circuitry. (MUX control was previously discussed.)

b. Enable signals are applied to the OTC, SMC, and HVS. These functional components are activated during test execution only to extend component lifetime and conserve Spacelab power.

c. The logic gates in the LOAD control lines are gated off, thus preventing the entry of new commands into memory during test execution.

d. The clock is gated to the SPE and the two interval timers. The function of the clock and the utilization of its output by the SPE and two interval timers are described in the following paragraph.

The clock provides the basic timing information for GFFC operation. The SPE processes the clock output and conveys it to the CDP for imaging of elapsed test time (see Section 3.8.1). The two interval timers are programmable dividers which allow OCP selection of the MUX channel switching rate and camera trigger rate (see Sections 3.6.1 and 3.6.2). It will be recalled that the fluid flows and data recordings which occur during each GFFC voltage step constitute an experiment (see Section 3.1). Since the MUX output controls the HVS which, in turn, controls the voltage steps, the MUX switching rate (as set by programmed command) determines experiment duration.

At test completion, the reset and initialization circuitry returns the flip-flop to its original polarity. This return has four consequences:

a. MUX control is returned to the rotary switch.

b. Disable signals are applied to the OTC, SMS, and HVS.

c. The logic gates in the LOAD control lines are gated on, allowing the entry of new commands into memory.

d. The clock is gated off.

Two reset modes are provided. Automatic reset is the expected mode and is accomplished by maintaining an electronic count of the experiments performed. At the completion of 10 experiments (i.e., one test), the counting device overflows and triggers a one-shot. This one-shot applies reset signals as required.

Manual reset is the alternate mode and is effected via a front panel pushbutton switch (see Section 3.6.1). Depression of this switch triggers the one-shot and allows premature test termination. Reset by either mode is required at test termination to ready the GFFC for further tests.

At instrument turn-on, the reset and initialization circuitry provides for proper setting (initialization) of GFFC circuit elements. Initialization is accomplished by triggering of the one-shot described previously in connection with the automatic and manual reset modes. Initialization is in essence a third form of reset.

Numerous one-shots not related to the reset and initialization circuitry are provided in the sequencer. Each of these is associated with a pushbutton switch, and their purpose is to prevent contact bounce from adversely affecting sequencer operation.

A logic gate disables the camera trigger when the MODE switch is placed in the CALIBRATE position (see Section 3.6.1). Thus calibration may proceed without film waste or unnecessary operation of the camera advance mechanism.

The timing and control section provides various status signals to the SPE for ultimate display on the ODP.

3.3.2 High Voltage Supply Description

The HVS is a digitally programmable source of sinusoidal, constant frequency voltage. It is comprised of an oscillator, buffer amplifier, step-up transformer, and variable gain feedback circuitry (Fig. 3-6).

The oscillator provides the basic sinusoidal signal for the HVS. Its output is applied to the transformer via a buffer amplifier. The signal appearing at the transformer secondary constitutes the HVS output.

The feedback circuitry serves two purposes: gain control and stabilization. FET switches in the feedback circuitry are turned on and off in response to the programmable digital word received from the sequencer. As a consequence, various combinations of feedback resistors may be placed into the circuit. Gain control is thus obtained.

The capacitors are representative of the circuitry required to insure stable operation of the supply, and the variable resistors are for calibration.

A status signal is provided to the ODP and CDP via the SPE to enable monitoring and recording of the HVS output voltage level.

3.4 Mechanical Description

The GFFC is mounted in a standard 48.26 cm (19 in.) rack (Spacelab supplied) and is composed of two mechanically separate components. These components are the instrument proper and the front panel (Fig. 3-1). The instrument proper is described in the next paragraph, and the front panel is described in Section 3.6.

The instrument proper is composed of a baseplate section and a turntable section (Fig. 3-2). The baseplate section consists of the electronics package, spin motor, and slip ring assembly, as well as the baseplate to which each of these components is mounted. The electronics package communicates with the front panel through wire harnesses. The spin motor is coupled to the slip ring assembly to provide rotation of the turntable section.

The turntable section is composed of the illuminator mounting post, sphere assembly, sphere housing, HVS, ATCS, and OTCS as well as the turntable to which each of these components is mounted. The sphere assembly, illuminator mounting post, sphere housing, and HVS are on the upper turntable

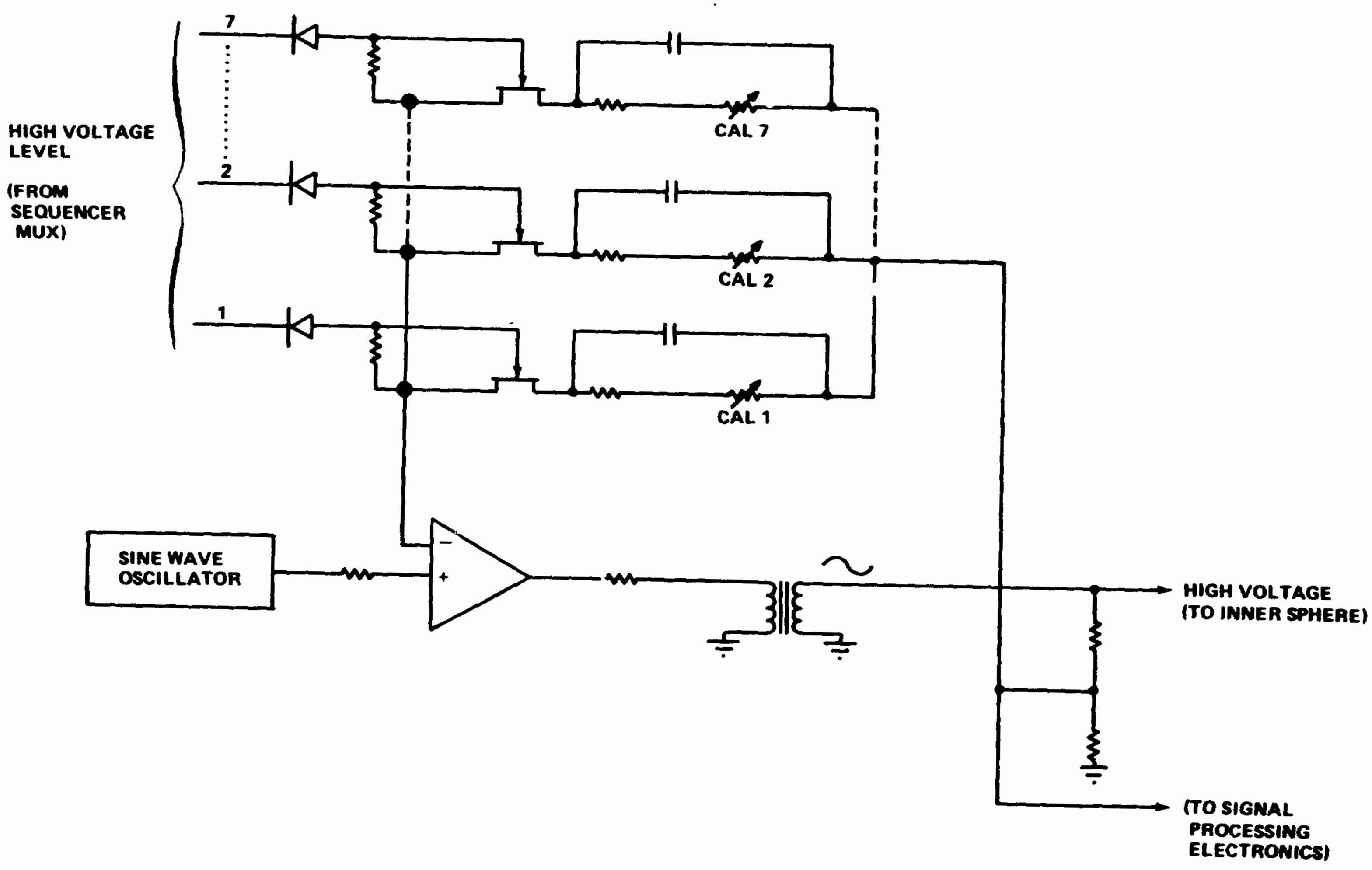

Figure 3-6. High voltage supply.

surface, and the ATCS and OTCS are on the lower surface. The slip ring assembly prov'des the electromechanical interface between the turntable and baseplate sections. The HVS is placed on the turntable, separated from the baseplate-mounted electronics package to avoid bringing a high voltage line through the slip ring assembly. Wires and wire harnesses connect the slip ring assembly with the turntable mounted components.

The illuminator mounting post provides an attachment point for the camera light source. The sphere assembly fits over the illuminator mounting post such that the light source is positioned centrally within the concentric spheres. The sphere assembly may be removed as a unit from the turntable to enable maintenance replacement of the light source.

The sphere housing forms a protective shell around the sphere assembly to contain the dielectric fluid and temperature control oil in the event of sphere breakage. The housing also forms a barrier to heat transfer, allowing a temperature-controllable air pocket to surround the sphere assembly (see Sections 3.2 and 3.5). An O-ring hermetically seals the housing at its attachment to the turntable.

The film camera is mechanically mounted to sphere housing. The aperture in the housing through which the camera lens projects is hermetically sealed (see Section 3.7).

3.4.1 Sphere Assembly Description

The sphere assembly is composed of a sphere mounting post, two temperature sensors, two fluid lines, three electrical lines, lens cap, and inner and outer spheres. The sphere mounting post is a hollow tube which joins the two spheres at one end with the turntable at the other. The two temperature sensors are attached to the mounting post. One sensor projects from the post into the inner sphere volume, and the other projects into the air pocket between the housing and outer sphere (see Section 3.4). The fluid lines connect the inner sphere volume with the OTCS, and one of the electrical lines connects the inner sphere surface with the HVS. A second electrical line joins the inner sphere temperature sensor to the OTCS. Each of these fluid and electrical lines passes from the inner sphere to its respective location via the mounting post. Oil seals prevent leakage at the points where the lines pass through the inner sphere/mounting post interface.

The lens cap is mounted on top of the sphere mounting post to provide uniform dispersion of the illuminator light (see Section 3.7).

The spheres are each composed of a glass upper hemisphere bonded to an aluminum lower hemisphere. The inside glass surface of the outside sphere and the outside glass surface of the inside sphere are coated with a nonreflective, transparent, electrically conductive material. In addition, the inside glass surface of the inner sphere is inscribed with a grid composed of latitudinal and longitudinal lines.

The aluminum lower hemispheres are bonded to the sphere mounting post. The aluminum half of the outside sphere is fitted with a fill and drain plug for the dielectric fluid.

3.5 Thermal Description

The GFFC is provided with an ATCS and an OTCS. The former maintains the outer sphere temperature at a constant 25°C, while the latter maintains the inner sphere temperature at a fixed level above 25°C as dictated by programmed command.

The ATCS consists of the ATC, thermoelectric cooler, fan, plenum, heat strips, ducting, and fittings. The fan, cooler, and heat strips are located in the plenum, and the ducting brings air from the plenum to the outer sphere environment and vice versa.

The ATC provides a fixed dc current to the thermoelectric cooler. The thermoelectric cooler provides a cold surface of a given temperature as a function of the imposed current. The cold surface causes the plenum air temperature to drop.

The ATC also provides a signal to the heat strips. The heat strips warm the air as a function of applied current. By comparing the sensed air temperature to an internal reference, the ATC applies sufficient current to the strips to maintain the outer sphere temperature at 25°C. The heat strip/thermoelectric cooler combination provides better dynamic response and smaller steady state errors than is possible with heat strips alone.

The fan is a small, electrically driven unit which maintains continuous air recirculation to achieve uniformity of temperature throughout the ATCS domain.

The OTCS consists of the OTC, pump, accumulator, fluid reservoir, oil, thermoelectric cooler, heat strips, piping, and fittings. The thermoelectric cooler is thermally bonded to the oil reservoir, and the heat strips are suspended within it. The piping connects the pump, oil reservoir, accumulator, and inner sphere.

The operation of the OTCS is analogous to the operation of the ATCS described earlier. However, the OTC reference is programmable via the OCP (see Sections 3.6.1 and 3.6.2). Therefore, the temperature level of the inner sphere oil may be varied as desired.

The pump is a small, electrically driven unit which, like the fan, provides continuous recirculation to maintain uniformity of temperature. The accumulator prevents cavitation at the pump input and also compensates for thermal expansion and contraction of the oil.

The Environmental Control System of the Spacelab provides a forced-air cooling loop for general cooling of the entire rack-mounted GFFC. Air enters the rack from the Spacelab supply duct, cools the equipment, and is then drawn through to the return duct. The ducting and fittings associated with this cooling loop are Spacelab supplied.

3.6 Front Panel Description

The front panel is comprised of the OCP and ODP. The OCP consists of controls and switches, while the ODP consists of indicators only (Fig. 3-7).

3.6.1 Front Panel Switches

a. TEMPERATURE SET, SPIN RATE SET, VOLTAGE SET, EXPERIMENT DURATION SET, and TRIGGER RATE SET: Thumbwheel switches to program test parameters.

b. TEMPERATURE LOAD, SPIN RATE LOAD, VOLTAGE LOAD, EXPERIMENT DURATION LOAD, and TRIGGER RATE LOAD: Pushbutton switches to transfer information from thumbwheel switches to instrument memory.

c. EXPERIMENT SELECT: Rotary switch to enable selection of the memory register into which the programmed voltage is to be entered (ee Section 3.3.1).

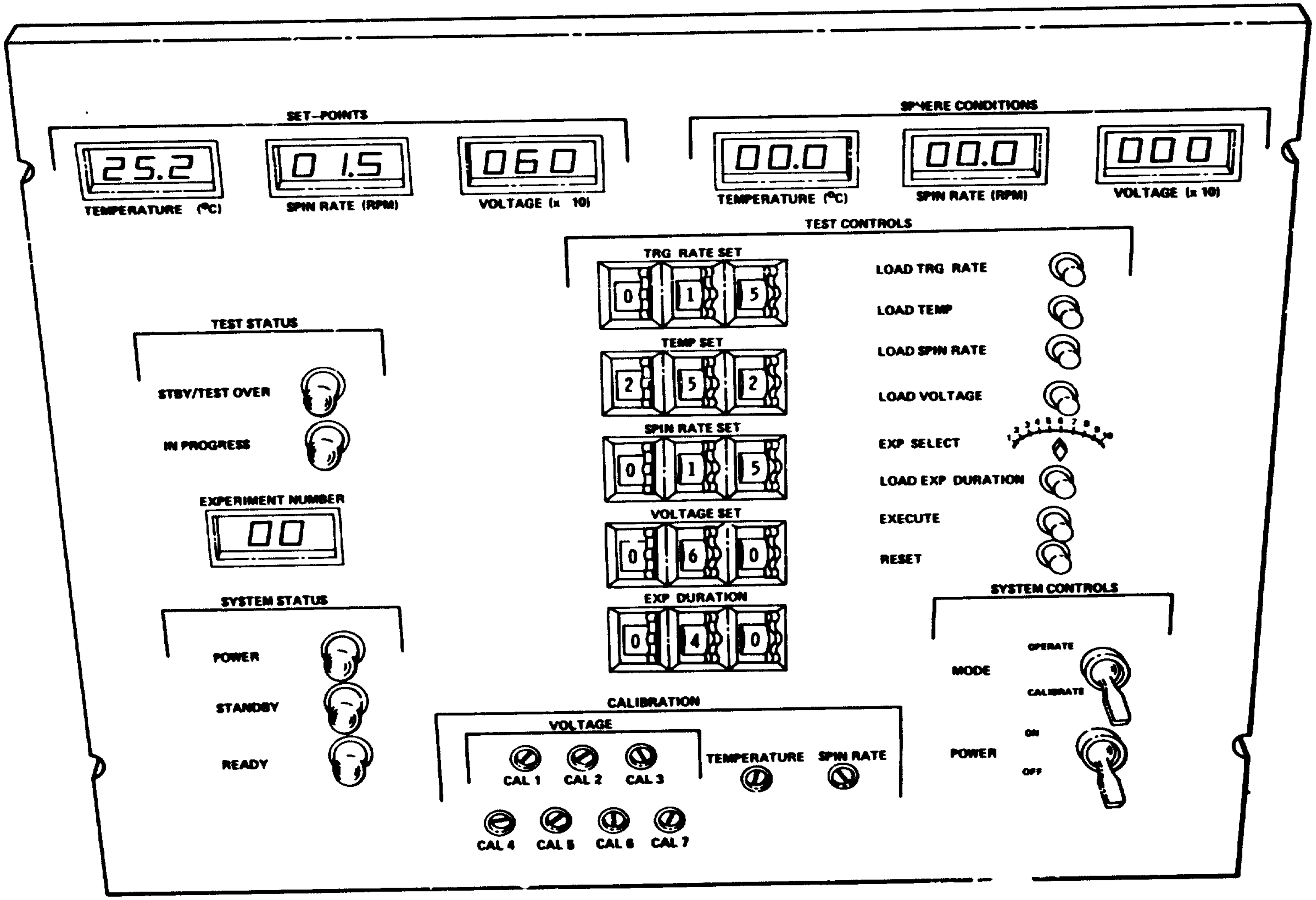

Figure 3-7. Front panel.

d. EXECUTE: Pushbutton switch to initiate test.

e. RESET: Pushbutton switch to allow premature test termination.

f. MODE: Toggle switch to disable camera trigger during calibration procedures.

g. POWER: Toggle switch to control primary power to instrument.

3.6.2 Front Panel Controls

CALIBRATION: Screwdriver-adjust potentiometers to allow field calibration of the GFFC.

3.6.3 Front Panel Indicators

a. TEMPERATURE SET-POINT, SPIN-RATE SET-POINT, and VOLTAGE SET-POINT: Provide visual display of the commands programmed into memory. The displayed voltage command is a function of the EXPERIMENT SELECT switch position (see Section 3.6.1).

b. SPHERE TEMPERATURE, SPHERE SPIN RATE, and SPHERE VOLTAGE: Provide the operator with visual display of actual sphere conditions.

c. STBY/TEST OVER: Glows when system power is on but a test is not in execution.

d. STANDBY: Glows when system power is on but the outer sphere temperature is not 25°C. This indicator normally glows briefly subsequent to power turnon; indication at any other time denotes a possible instrument malfunction.

e. READY: Glows when system power is on and the outer sphere temperature is 25°C.

f. EXPERIMENT NUMBER: Indicates the number of the experiment in the test sequence currently in progress.

g. POWER: Glows when instrument power is on.

3.7 Optical Description

The optical system consists of a camera and illuminator. The camera is mounted to the hermetic housing. The housing is provided with an aperture through which the camera lens projects. The camera is positioned such that the optical axis of the lens is collinear with the radial line passing through sphere coordinate 45° N latitude.

The camera is modified to provide a data display mount. This mount accepts the camera display panel. The result is that the film frame is divided into two sections. One section records the data displayed on the panel; the other section records the flow patterns existing within the concentric sphere gap. The camera is equipped with a motor drive to permit electrical triggering of the film advance mechanism.

The illuminator is the light source for the camera. It is centered in the inner sphere atop the illuminator mounting post (see Section 3.4). The illuminator is powered during film imaging only. Thus a negligible heat load is generated and Spacelab power is conserved. Current limiting provides "soft" starts to extend illuminator lifetime.

3.8 Camera Display Panel

The camera display panel is attached to the data display mount (see Section 3.6) and consists of indicators only.

3.8.1 Camera Display Panel Indicators

a. SPHERE TEMPERATURE, SPHERE SPIN RATE, SPHERE VOLTAGE, and EXPERIMENT NUMBER: Provide same information as analogous front panel displays (see Section 3.6.3).

b. ELAPSED TIME: Provides display of elapsed test time.

3.9 Interface Description

The GFFC has mechanical, electrical, and thermal interfaces with the Spacelab. The mechanical interface consists of the physical connection between the GFFC and the Spacelab experiment rack, and the electrical interface consists of the GFFC connection with the Spacelab power distribution system. The thermal interface consists of the heat load transferred from the GFFC to the Spacelab air cooling loop.

The mechanical interface is of sufficient strength to withstand the mechanical loading imposed upon the GFFC during the Spacelab mission (see Section 5.2). The electrical interface supplies the power required for GFFC operation (see Section 5.3). The air cooling loop removes the heat generated by the GFFC. Since the sole source of GFFC power is electrical, the heat load imposed upon the air cooling loop by the GFFC is limited to the electrical power consumption level (see Section 5.8).

4.0 OPERATING PROCEDURE

The following is a typical operating procedure for the GFFC.

a. Instrument power switched on.

b. Calibration check performed. Calibration provided if necessary.

c. Film loaded into camera.

d. Temperature command entered and loaded.

e. Spin-rate command entered and loaded.

f. EXPERIMENT SELECT switch placed in position 1. Voltage command entered and loaded.

g. Step "f" repeated for switch positions 2 through 10.

h. EXPERIMENT DURATION entered and loaded.

i. CAMERA TRIGGER RATE entered and loaded.

j. EXECUTE command given (READY indicator must be on; see Section 3.6.3).

k. RESET command given if premature test termination desired.

l. Instrument power switched off or step "d" returned to for further tests.

m. Film unloaded from camera, marked, and stored.

During tests, the instrument operator is expected to survey the various panel indicators for malfunction detection. Also, the operator is expected to remain aware of film status and load replacement film is needed.

5.0 REQUIREMENTS

The GFFC engineering requirements are divided into 11 areas: performance, environmental, calibration, memory, electrical, mechanical, fluid, interface, reliability and quality, test, and safety.

The following paragraphs describe the requirements of each of these areas.

5.1 Performance

The GFFC performance requirements are divided into nine areas:

a. Spin control requirements

b. Air temperature control requirements

c. Oil temperature control requirements

d. High voltage supply requirements

e. Programming entry and command lock-out requirements

f. Experiment duration requirements

g. Camera trigger requirements

h. Clock requirements

i. Sphere stability requirements.

The following paragraphs describe the requirements of each of these areas.

5.1.1 Spin Control Requirement

a. Range: 0.3 to 3.0 rad/s.

b. Resolution: 100 steps of equal increment over the dynamic range.

c. Accuracy (steady state and dynamic, combined): 0.1 percent set-point. Shall be capable of maintaining this accuracy level for at least 300 h following field calibration.

d. Dynamic Response: 10 s maximum to reach within 99 percent of set-point speed for a step change exceeding 10 percent.

5.1.2 Air Temperature Control Requirements

a. Temperature Level: 25.0°C, nonadjustable.

b. Accuracy (steady state and dynamic, combined): ±0.2°C. Must be capable of maintaining this level of accuracy for at least 300 h following field calibration.

c. Warm-up Time: Shall be capable of achieving 25.0 ± 0.2°C within 5 min of instrument turn-on.

5.1.3 Oil Temperature Control Requirements

a. Range: 0.0°C to 30.0°C with respect to outer sphere temperature.

b. Resolution: 101 steps of equal increment over the dynamic range.

c. Accuracy (steady state and dynamic, combined): ±0.2°C. Shall be capable of maintaining this level of accuracy for at least 300 h following field calibration.

d. Dynamic Response: 5 min maximum to reach within ±0.2°C of set-point temperature for a step change exceeding 5 percent. One min maximum to reach within ±0.2°C of set-point for a step change less than or equal to 5 percent.

5.1.4 High Voltage Supply Requirements

a. Range: 0 to 8000 V.

b. Resolution: 81 steps of equal increment across dynamic range.

c. Accuracy (steady state and dynamic, combined): 0.5 percent of set-point. Shall be capable of maintaining this accuracy level for at least 300 h following field calibration.

d. Waveform: sinusoid, 100 ± 3 Hz.

e. Total distortion: <4 percent

f. Maximum noise: 0.5 percent of set-point peak amplitude over the frequency range 0.001 to 100 kHz.

g. Dynamic response: 10 s maximum to reach within 0.5 percent of set-point for any percentage step change.

5.1.5 Programming Entry and Command Lock-Out Requirements

The GFFC shall be reprogrammable via front panel thumbwheel switches or equivalent. Command signals other than RESET entered cotemporally with an in-progress test shall be electrically ignored. The GFFC shall be responsive to commands entered only during nontest period.

5.1.6 Experiment Duration Requirements

a. The Experiment duration shall be adjustable on a test-by-test basis. It is not required that the duration be variable from experiment to experiment within a given test sequence.

b. Range: 5 to 50 min.

c. Resolution: 10 steps of equal increment over the range.

d. Accuracy: 1.0 percent of set-point. Shall be capable of maintaining this accuracy level for at least 300 h following field calibration.

5.1.7 Camera Trigger Requirements

a. Range: 5 to 3000 s

b. Resolution: 60 steps of equal increment over range.

c. Accuracy: 1.0 percent of set-point total maximum error. Must be capable of maintaining this accuracy level for at least 300 h following field calibration.

5.1.8 Clock Requirement

Accuracy: 0.1 percent maximum frequency error. Shall be capable of maintaining this accuracy level for at least 300 h following field calibration.

5.1.9 Sphere Stability Requirement

Radial excursions of the concentric spheres shall be limited to ±0.05 cm during GFFC operation.

5.2 Environmental Requirements

a. Temperature and Humidity — Table 5-1 describes the temperature and humidity (T& H) environmental limits for the GFFC. These limits are given in terms of operating and storage T& H ranges. Any combination of T& H within these ranges may occur. The GFFC shall be capable of meeting all performance requirements of Section 5.1 when operated within the operating T& H ranges. Further, the GFFC shall incur no damage when stored within the storage T& H ranges. Maximum storage time is TBD.

b. Vibration — The GFFC shall incur no damage when subjected to the random vibration environment described in Table 5-2.

c. Acoustic environment — The GFFC shall incur no damage when subjected to the acoustic environment described in Figure 5-1.

d. Acceleration — The GFFC shall incur no damage when subjected to 10-g static loading along each of the three principal axes.

e. Shock — The GFFC shall be of sufficient physical integrity to preclude hazards to personnel in the event of crash load.

f. GFFC external surface — No external surface of the GFFC shall exceed 45° C unless provided with protective guards. No external surface of the GFFC shall be cooler than 25°C or ambient Spacelab temperature, whichever is lower.

TABLE 5-1. TEMPERATURE AND HUMIDITY LIMITS

Factor	Operating	Storage
Temperature	15 to 30°C	TBD
Humidity	20 to 70 percent	TBD

TABLE 5-2. RANDOM VIBRATION ENVIRONMENT

Frequency	Level
20 Hz	0.10 g^2/Hz
20 to 80 Hz	+3 dB/oct
80 to 350 Hz	0.040 g/Hz
350 to 2000 Hz	-3 dB/oct
2000 Hz	0.0070 g^2/Hz
Total Duration = 3 min	

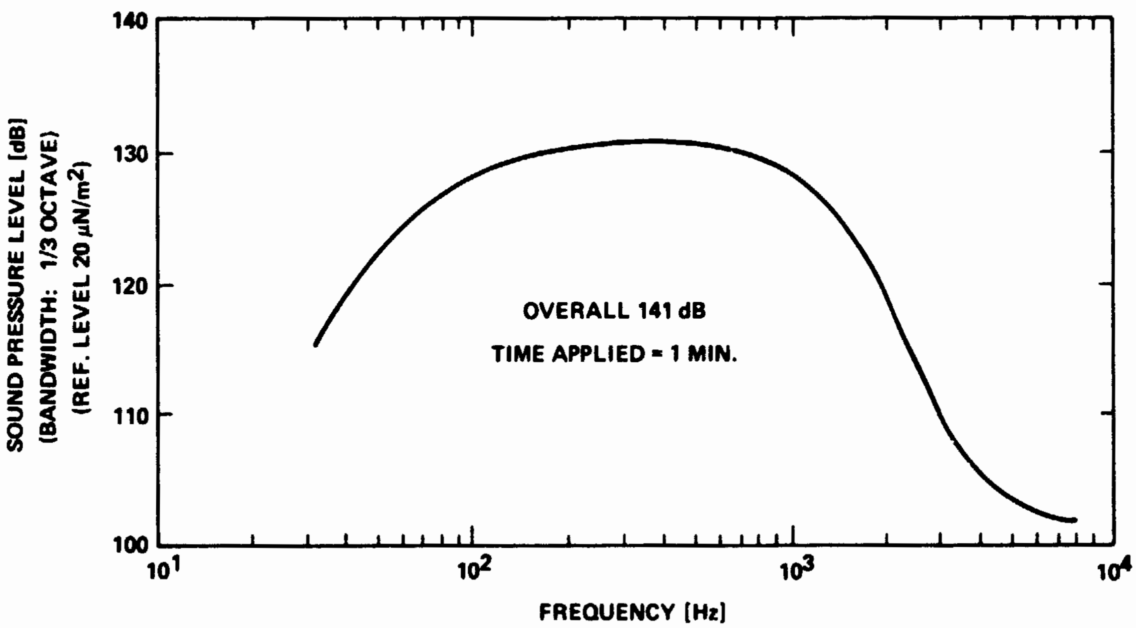

Figure 5-1. Acoustic environment.

5.3 Calibration Requirements

The GFFC shall have provisions for field calibration for the following functions: spin rate, high voltage, outer sphere temperature, and inner sphere temperature.

The clock shall be utilized to provide timing information to the experiment duration control circuitry and the camera trigger rate circuitry, thus obviating the need for separate calibration for these functions.

Calibration shall be accomplished by way of screwdriver-adjust front panel controls. The instruments panel display indicators shall be utilized to provide any required metering. Standard references or other devices required in the calibration procedure shall be integral to the instrument. No external test equipment may be utilized.

5.4 Memory Requirements

The simulation instrument shall contain 12 memory storage registers. The registers shall be allocated as follows:

Quantity	Stored Command
1	Spin-rate
1	Temperature
10	Voltage

5.5 Electrical Requirement

a. The two primary power sources described in Table 5-3 are available for simulation instrument use. The designer is given his option to utilize either or both sources.

b. The simulation instrument power consumption shall be limited to the values shown in Table 5-4.

c. The simulation instrument shall not generate electrical interference on the 28 Vdc primary power lines above the limits described in Table 5-5.

TABLE 5-3. PRIMARY POWER SOURCES

ac Power	dc Power
Voltage: 115/200 Vac ± 5 percent Outputs: 3 phases + neutral Harmonic Distortion: 5 percent	Voltage: 28 ± 4 Vdc Noise: 1.8 Vp-p 30 Hz to 7 kHz, decreasing to 0.6 Vp-p at 50 kHz, then flat at 0.6 Vp-p to 500 kHz (quasi-sinusoidal) Spiking: ±50 V, 10 ms duration

TABLE 5-4. POWER CONSUMPTION LIMITS

Mode	Average (W)	Peak (W)
STBY/test over	20	70
In progress	50	70
Calibrate	50	70

TABLE 5-5. GENERATED NOISE LIMITS

1. 1.5 V (rms) at any discrete frequency between 30 Hz and 3 kHz, and 1.5 Vp-p in the frequency range of 3 to 100 kHz.

2. Primary bus transients measured on the positive lead of the 28 Vdc powerline shall not exceed ±28 Vdc and 50 s duration.

3. Current rise and fall under load-switching conditions shall be as slow as practical and shall never exceed a rate of 5 amp/μs.

d. Grounding and isolation — The simulation instrument shall maintain a circuit isolation of at least 1 MΩ (0 to 60 Hz) from input power leads to chassis and from internal signal return to chassis. It is also required that all switched powerlines be provided an electrostatic discharge path to chassis not exceeding 100 MΩ.

5.6 Mechanical Requirements

a. Size — The GFFC shall be no more than 48 cm (19 in.) deep, 92 cm (36 in.) high, and mount is a standard 48 cm (19 in.) rack (the rack shall be Spacelab supplied).

b. Weight — The GFFC shall weigh no more than 38.5 kg (85 lb).

c. Seals — All seals associated with the concentric sphere gap, ATCS, and OTCS shall be hermetic or oil-tight as applicable.

5.6.1 Sphere Requirements

a. Radius — Inner sphere, 2.22 ± 0.005 cm, inside diameter. Outer sphere 3.15 ± 0.005 cm inside diameter (sphere radii are tentative; however, tolerances are firm).

b. Material — Upper hemisphere, Pyrex glass. Lower hemispheres, aluminum.

c. Coating — The inside surface of the glass half of the outer sphere and the outside surface of the glass half of the inner sphere shall be coated with a transparent, electrically conductive material. This material shall be equal or equivalent to the Perkin-Elmer "Conductran" coating.

d. Stability — The spheres shall be capable of remaining within the radial tolerances described in "a" above when maintained within the T&H operating limits of Table 5-4. The coating described in "c" above shall remain stable when maintained within the T&H storage limits of Table 5-4.

e. Grid Lines — The inner surface of the glass half of the inner sphere shall be inscribed with longitudinal and latitudinal lines both spaced at 5° (tentative) intervals. Each line shall be within TBD of true position.

5.7 Fluid Requirements

a. The concentric sphere gap shall be filled with Dow Corning 200 silicone oil. Th. properties of this oil are described in Table 5-6.

b. The designer is free to utilize the fluid of his choice for the OTCS subject to safety requirements of Section 5.10.

TABLE 5-6. PROPERTIES OF DOW CORNING 200 SILICONE OIL

Coefficient of Kinematic Viscosity	1.0×10^{-2} cm^2 s^{-1}
Coefficient of Molecular Heat Conduction	6.4×10^{-4} cm^2 s^{-1}
Coefficient of Volumetric Expansivity	1.17×10^{-3} °C^{-1}
Density	0.873 gm cm^{-3}
Thermal Coefficient of Dielectric Permittivity	1.0×10^{-3} °C^{-1}
Isobaric Specific Heat	0.45 cal gm^{-1}

5.8 Interface Requirements

a. Mechanical — The mechanical interface between the GFFC and Spacelab experiment rack shall be of sufficient strength tc withstand mission acceleration loads (see Section 5.2) and satisfy Spacelab safety requirements (see Section 5.10).

b. Electrical — The experiment power distribution system shall be capable of supplying the electrical power required to operate the GFFC (see Table 5-4).

c. Thermal — The Spacelab air cooling loop shall be capable of removing 50 W of heat, average (70 W, peak) while maintaining the experiment rack temperature at or below 40°C.

5.9 Reliability and Quality Requirements

The GFFC shall be placed into Earth orbit as a part of the Spacelab experiment pool. As such, it is of paramount inportance that scrupulous attention be given to the areas of reliability and quality. Specific MSFC requirements in this direction are presently being formulated and will be supplied at a later date.

5.10 Test Requirements

The GFFC shall be tested to insure and demonstrate that all requirements stated in this and applicable documentation are satisfied in the following categories:

a. Performance

b. Mechanical

c. Electrical

d. Environmental

e. Safety

f. Interface (GFFC/Spacelab 1)

g. Calibration.

Other and presently unidentified test categories may become necessary during the GFFC development program.

5.11 Safety

The safety assurance for Spacelab 1 payloads is still under discussion between ESA and NASA; however, an ESA safety requirements proposal is available [5-1]. In addition, a NASA safety policy and requirements for payloads using the Space Transportation System have been enunciated by Mr. John F. Yardley [5-2]. In lieu of a specified NASA safety policy and associated requirements for Spacelab payloads, References 5-1 and 5-2 shall be used as guidelines for addressing safety considerations relative to the GFFC design and operation.

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APPENDIX

THEORETICAL BASIS FOR RADIAL BODY FORCE SIMULATION WITH DIELECTRIC FLUIDS IN ELECTRIC FIELDS

The key to successful laboratory modelling of planetary scale motions on a sphere is to replace the normal terrestrial laboratory buoyancy force, which is unidirectional, with a radially directed force which is, like the buoyancy force in a liquid, just proportional to temperature. Now in a dielectric fluid, the body force F has a buoyancy term arising from expansion and an electromagnetic polarization force term, namely

$$\vec{F} = -1/2\, E^2 \nabla \epsilon + g\rho \nabla \phi \qquad (1)$$

where

E is the magnitude of the imposed electric field,

ϵ is the dielectric permittivity,

ρ is the fluid density,

g is the magnitude of background accelerations acting in a direction $\nabla\phi$ (ϕ being a potential function).

For the fluid used in our experiment (a silicone oil), the equations of state are $\rho = \rho_o [1 - \alpha(T - T_o)]$ and $\epsilon = \epsilon_o [1 - \beta(T - T_o)]$ where α and β are constants and T_o is the ambient temperature about which experiments are run (typically 22°C) where $\epsilon = \epsilon_o$ and $\rho = \rho_o$.

Now the velocity field in an incompressible fluid (which is an accurate model for oceanic and shallow atmospheric flows and is a primary assumption in most all analytical studies of planetary circulation), with no-slip boundary conditions, is affected only by the curl of $\vec{F}$. That is

$$\text{curl } \vec{F} = \nabla T \times \left(-\frac{1}{2} \epsilon_o \beta \nabla E^2 + g\rho_o \alpha \vec{Z}\right) \qquad (2)$$

where $\vec{Z}$ is a unit vector directed along $\nabla\phi$. The electromagnetic and buoyancy terms are proportional to gradients in T, but the former can be directed by the geometry of the imposed electric field. The experiment takes place in the upper hemisphere of a spherical capacitor. This is shown in Figure 3-2. The potential difference across the electrically conducting inner and outer spheres is V_1, and the temperature difference is ΔT. The inner and outer surfaces are also good thermal conductors. A temperature gradient can also be maintained along the inner and outer spheres between poles and equator.

In such a bounded configuration, E depends only on radius r (except near the feed-through region; however, experiments run in the upper hemisphere experience a field which is effectively radial as long as the gap of the annulus is not too big). It has the form

$$\vec{E} = D_1 D_2 V_1 r / (D_2 - D_1) r^2 \ . \tag{3}$$

Thus, the torque term in curl $\vec{F}$ resulting from electromagnetic effects is exactly analogous to the force resulting from buoyancy except that it is perpendicular to the radial direction. Thus, we call the electromagnetically derived term a "radial gravity." Ideally, one would like to choose parameters such that radial gravity dominates over background gravity [second term on right side of equation (1)]. The ratio of these forces is

$$2\epsilon_o \beta (D_1 D_2 V_1)^2 \Big/ \left[g\alpha\rho_o (D_2 - D_1)^2 \frac{(D_1 + D_2)^5}{16} \right] \ . \tag{4}$$

For a reasonably sized apparatus (D_1 and D_2 must be chosen so that dynamical similarity is maintained with respect to the theoretical models of interest), the radial force will dominate at sufficiently large V_1. Because of the nature of the fluids available for use in the experiments, excessive voltages are necessary to make the radial gravity field the required two orders of magnitude larger than the background gravity in the terrestrial laboratory. However, in a near zero-g environment, reasonable voltages can be used with known materials to produce an essentially radial gravity field.

APPROVAL

INSTRUMENT CONCEPT FOR GEOPHYSICAL FLUID FLOW EXPERIMENTS ON THE FIRST SPACELAB MISSION

By Richard S. Rodkin and George H. Fichtl

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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